

**NUTRITIONAL, PHYSICAL AND SENSORY QUALITY OF EXTRUDED  
INSTANT WHITE SORGHUM-PIGEON PEAS GRUEL FLOUR**

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**A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE  
REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN FOOD  
QUALITY AND SAFETY ASSURANCE OF SOKOINE UNIVERSITY OF  
AGRICULTURE. MOROGORO, TANZANIA.**

**ABSTRACT**

Five varieties of white sorghum consumed in Tanzania namely, *Pato*, *Hakika*, *Tegemeo*, *Macia* and *Wahi*, non-complemented and complemented with pigeon peas at ratios 75:25 and 70:30 were extruded to produce instant porridge flour. The physical, nutritional, and sensory quality of the flour was evaluated. The physical quality parameters were: bulk density 0.5-0.7 gcm<sup>-3</sup>, viscosity 0.5-0.8dpas, water absorption index 0.04-0.6 g/g, water solubility index 24.1-41.2%; the nutritional composition was: crude fibre 3.3-8.9 g/100 g dry matter (DM), crude fat 0.5-3.6 g/100 g DM, ash 0.6-2.6 g/100 g DM, crude protein 9.5-14.1 g/100 g DM, carbohydrates 67.7-83.8 g/100 g DM, energy 323-397 kcal/100g. The addition of pigeon peas to sorghum increased the bulk density, viscosity and water solubility index in all varieties, while the water absorption index decreased. Complementation of sorghum with pigeon peas improved the nutritional quality of the composites flour. The digestibility of the instant flour ranged from 7.4 to 11.8 g/100 g DM. Complementation of sorghum flour with pigeon peas increased the mineral levels. The content of calcium, magnesium, potassium, copper, zinc and iron was 258-395, 255.1-336.2, 365.1-915.2, 0.1-0.4, 1.8-3.8 and 3.0-8.5 mg/100 g DM, respectively. The sensory evaluation of instant gruel prepared from all the formulations indicated that all formulations were acceptable. Therefore, the inclusion of pigeon peas improved the quality of sorghum instant porridge flour for young children and infants.

**DECLARATION**

I, ANGELINA BENEDICT MAHENGE, do hereby declare to the senate of the Sokoine university of Agriculture that this dissertation is my original work, done within the period of registration and that it has neither been submitted nor been concurrently submitted for a higher degree award in any other Institution.

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Date

The above declaration is confirmed by;

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Prof. Jovin K.Mugula  
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Date

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## ACKNOWLEDGEMENTS

First, I would like to thank the Almighty God for the good health, energy and courage to undertake this study.

I wish to express my thanks to my supervisor Professor Jovin K. Mugula for guidance and extrusion facilities. I humbly appreciate the love and encouragement, moral and financial support from my parents, Mr. and Mrs. Mahenge. I would like to thank Dr. Richard Mongi for his assistance in sensory evaluation.

I would like to acknowledge the assistance offered by laboratory staff in the Department of Food Technology, Nutrition and Consumer Sciences. Specifically, I would like to thank Engineer Isaack Balongejeja for assistance in extrusion cooking; Mr. Malogo Nkanwa, Stewart Mwayika and Mohamed Mohamed for nutritional, physical properties and sensory analyses.

I am grateful to my MSc. Food Quality and Safety Assurance classmates for the love, cooperation, motivation and encouragement in one way or another during the whole period of studies.

Last, but not least, I would like to thank my friends in the Department of Food Technology, Nutrition and Consumer Sciences who in one way or another helped me while undertaking this study, particularly, Domina Swai, Phillip Maswi, Mwanaaisha Ngawembela, James Chacha, Constancia Henry, Sarah Ngwere, Mary Jackline Odhiambo, Boaz Benedict, Clay Mhagama and Chrispin Sanga.

## **DEDICATION**

This work is dedicated to my beloved family Mr. and Mrs. MAHENGÉ and my young sister Louise Benedict for their love, encouragement and support.

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**LIST OF ABBREVIATIONS AND ACRONYMS**

ANOVA	Analysis of Variance
AOAC	Association of Official Analytical Chemists
CAC	Codex Alimentarius Commission
CHO	Carbohydrate
DM	Dry Matter
DPAS	Deci Pascal
FAO	Food and Agriculture Organization
FAOSTAT	Food and Agriculture Organization Corporate Statistical Database
HTST	High Temperature Short Time
KCAL	Kilocalories
Mg/g	Milligram per gram
PC	Principal Component
PCA	Principal Component Analysis
PLSR	Partial Least Square Regression
QDA	Quantitative Descriptive Analysis
RPM	Revolution per Minute
SPSS	Statistical Package for Social Sciences
SUA	Sokoine University of Agriculture
TBS	Tanzania Bureau of Standards
TZS	Tanzania Standards
UNU	United Nations University
USA	United States of America
USAID	United States Agency for International Development

USCP	United Sorghum Check off Program
WAI	Water Absorbing Index
WHO	World Health Organization
WSI	Water Solubility Index

## CHAPTER ONE

### 1.0 INTRODUCTION

#### 1.1 Importance of Sorghum

Sorghum (*Sorghum bicolor*) is one of the most important cereal crops in the supply of food energy. It ranks fifth with only four other starchy crops namely, maize, rice, potatoes and wheat, consumed more than sorghum (FAOSTAT, 2015). It is used extensively worldwide in food production systems (Waniska and Rooney, 2000). It is an important dietary component in Africa and Asia. Ethiopia is the top producer, Tanzania the second, and Uganda the third producer of sorghum in East Africa (Mugula *et al.*, 2011).

In Tanzania, it is an important cereal for food security especially in the central high plateau comprising Singida and Dodoma regions (Rowhani *et al.*, 2011). It is widely available especially in rural areas, and it is a cheap source of food compared to other such as soybeans. Shewale and Pandit (2011) reported that utilization of the sorghum can be classified mainly into two categories; human, animal food and industrial use. The main industries using sorghum are the animal feed sector, alcohol distilleries, and starch industries (Ashok *et al.*, 2011). It serves as an important source of cattle feed and fodder (Rooney and Miller, 2004).

Sorghum is an important traditional food that children are fed as complementary food in form of porridge and stiff porridge as a regular meal but yet underutilized (Mosha *et al.*, 2000). The high demand of products such as flour for snacks, porridge and beer making increases its commercial importance. Traditionally, sorghum processing involves milling, malting and fermentation to produce flours, alcoholic and non-alcoholic

traditional beverages and pre-ferments with little or no value addition (Byaruhanga *et al.*, 2014), hence sorghum-based products have been compromised by poor quality, safety and short shelf life (Mugula *et al.*, 2011).

Commercially sorghum is valuable due to its resistant nature; it is uniquely adapted to adverse growing conditions such as drought, poor fertility, water logging, high altitudes, salinity and wide soil range (Dillon *et al.*, 2007). Sorghum yields are not affected by short periods of drought as severely as other crops such as maize, because it develops its seed heads over longer periods of time, usually short periods of water stress do not prevent kernel development (Dicko *et al.*, 2006). Even in a long drought severe enough to hamper sorghum production, it still produces some seeds on smaller and fewer seed heads (Castro *et al.*, 2015).

Therefore, the future of sorghum enterprises is linked to its ability to resist drought, the contributions to food security, income growth, and alleviation of poverty in developing countries such as Tanzania, Ethiopia, and Uganda (Department of Agriculture, Forestry and Fisheries, 2014).

### **1.1.1 Nutrient composition and health benefits of sorghum**

Sorghum acts as a principal source of energy, protein, vitamins and minerals for millions of the poorest people living in drought regions, who cultivate sorghum for consumption at home and in certain cases for feeding their cattle (Mohammed *et al.*, 2011).

Some of the health benefits of sorghum include its ability to prevent certain types of cancer, helps control diabetes, offers a dietary option for people with celiac disease, improves digestive health, builds strong bones, promotes red blood cell development,

and boosts energy and fuel production (Awika *et al.*, 2003a). Sorghum is one of the best foods for dietary fibres for healthy digestive system. Typically, a single serving of sorghum contains 48% of a daily recommended intake of dietary fibre (more than 12 g); hence preventing cramping, bloating, constipation, stomach aches, excess gas, and diarrhoea (de Pee and Bloem, 2009). Furthermore, excess amounts of fibre in the body helps to scrape off dangerous cholesterol (LDL), which helps to improve heart health and protect the body from conditions like atherosclerosis, heart attacks, and strokes (Anderson, 2003).

The bran layer of the sorghum grains contains important antioxidants that are not found in other types of cereal grains (Dykes and Rooney, 2006). These antioxidants have been directly connected to reduced cases of various types of cancer, including esophageal cancer, among sorghum-eating people in comparison to people who regularly eat wheat and corn (Dykes and Rooney, 2006).

Antioxidants are the beneficial compounds that neutralize and eliminate free radicals, which often cause healthy cells in the body to mutate into cancer cells (Awika *et al.*, 2003b). Additionally, the tannin-rich bran of sorghum has anti-nutritional factors that inhibit enzymatic activity and the absorption of starch by the body. This inhibition can help to regulate insulin and glucose levels in the body (Awika and Rooney, 2004).

### **1.1.2 Limitations of sorghum**

Despite being important for its health benefits and food security combat, its underutilization is still observed. This is because sorghum has low nutrient density and it contains anti-nutritional factors that interfere with protein, carbohydrates and mineral metabolism thereby hindering its utilization (Mohammed *et al.*, 2011). It has low protein

quality and requires supplementation with high quality protein sources (Kikafunda *et al.*, 2006).

### **1.1.3 Improving sorghum utilization**

To improve sorghum utilization different processing techniques such as extrusion cooking, complementing with legumes can be employed. These techniques results in introduction of instant sorghum and sorghum-based products, such as bread, pasta, flour, and *togwa* which are rich in nutrients.

### **1.1.4 Industrialization and commercialization**

Industrialization and commercialization of traditional food crops have shown to contribute to economic growth and poverty reduction with direct benefits to small-scale farmers in East Africa. This is due to the increase in competition between the value-added products and the indigenous products. Hence, by doing so it increases the chance of good market of sorghum which later benefits the farmers and stakeholders in the commodity value chain (Mugula *et al.*, 2011).

Poor quality, safety and short shelf life of traditional products made from sorghum limit commercialization of this crop. This may be improved by up-scaling and out-scaling appropriate technologies, and applying modern scientific principles and technologies such as good manufacturing practices (Mugula *et al.*, 2011).

Complementing sorghum with legumes adds value in the commercialization of sorghum and its product. Legumes, pigeon pea in particular contains potential nutrients that in combination with sorghum form a dense nutrients rich formulation that is important for healthy.

## **1.2 Pigeon Pea and Its Importance**

Pigeon pea (*Cajanus cajan*) grow in a variety of agro-ecological zones, and are well adapted to semi-arid climate conditions (Troedson *et al.*, 1990). It is a tropical grain legume grown for food, feed and soil fertility improvement (Kundy *et al.*, 2015). It is mainly grown in India and in tropical and sub-tropical regions of Africa, Asia and America (Kundy *et al.*, 2015). In sub-Saharan Africa, it is widely grown in Tanzania, Kenya, Uganda, Malawi and Mozambique for subsistence, domestic and international markets, it is important for managing food security and nutritional situation (Karanja, 2016).

Pigeon pea grows quickly and tolerates unfavorable conditions including poor soil quality and drought. These characteristics make pigeon pea a great option for increasing family nutritional security and maintaining livestock health, particularly during the lean months between harvests.

Pigeon pea is widely known for its use as food. Immature pods, immature seeds, and the mature seeds can be consumed (Emefiene *et al.*, 2014). The seeds are used whole, de hulled, or ground to flour. Immature pigeon peas are edible, but contain less nutritional value than mature peas. Pigeon peas may be sprouted to increase its digestibility and change its flavor (Emefiene *et al.*, 2014).

### **1.2.1 Nutritional composition**

Pigeon pea is a good source of protein, dietary fibre and various vitamins and minerals; thiamin, magnesium, phosphorus, potassium, copper, and manganese (Emefiene *et al.*, 2014). Pigeon pea is cholesterol free, and has low saturated fats and sodium content. This makes pigeon pea like other legumes a healthy substitution for meats. In combination

with grains, pigeon peas constitute a well-balanced human diet (Manyasa *et al.*, 2009). Pigeon pea contains high amounts of vitamin B, carotene, and ascorbic acid which are deficient in cereals; therefore, pigeon pea has a good supplemental value of cereal-based diet (Faris and Singh, 1990).

Pigeon pea is a rich source of lysine but deficient in the sulfur-containing amino acids methionine and cysteine. Cereal grains contain sufficient levels of methionine and cysteine. Faris and Singh (1990) reported that pigeon pea improves the amino acid score for lysine in rice and wheat based diets, and for threonine, leucine, and isoleucine in wheat-based diet when used in a 70:30 cereal: pigeon peas ratio.

### **1.2.2 Limitations of pigeon peas**

Peas are locally affordable but underutilized grain legume because of the hard to cook phenomenon and the presence of anti-nutrients that limit its utilization (Mulualem *et al.*, 2012).

### **1.3 Complementary Foods**

These are foods that are readily consumed and digested by the young child and provide addition nutrients to meet all the growing child's needs (WHO, 2002). These foods are mostly given to young children after six months of exclusive breastfeeding. It is at this period when breast milk alone is no longer sufficient to meet all nutritional requirements of the child (WHO/OMS, 2000). After six months, the child needs more vitamins, minerals, proteins and carbohydrates than are generally available from breast milk alone (Michaelsen *et al.*, 2000).

Any non-breast milk foods or nutritive liquids that are given to young children during this period are defined as *complementary foods*, and *complementary feeding* is the

process of introducing these foods (WHO/OMS, 2000). It should be *timely*, meaning that foods are introduced when the need for energy and nutrients exceeds what can be provided through exclusive and frequent breastfeeding; *adequate*, meaning that foods provide sufficient energy, protein, and micronutrients to meet a growing child's nutritional needs; *safe*, meaning that foods are hygienically stored and prepared, and fed with clean hands using clean utensils and not bottles and teats; *properly fed*, meaning that foods are given consistent with a child's signals of appetite and satiety, and that meal frequency and feeding method actively encouraging the child to consume sufficient food (WHO, 2002).

Lack of quantity and quality complementary foods, poor child-feeding practices, and high rates of infections contributes to health problems such as growth impairment amongst children. Complementing cereals with legumes or pulses improves the nutritional value since legumes and pulses are rich in proteins, amino acids, calories, minerals and vitamins (Hamid *et al.*, 2016). The knowledge of complementing cereals with legumes has not only led to improved nutritional quality but also has promoted consumer acceptance of the complementary products.

Complementing sorghum with pigeon pea to formulate the instant gruel flour can be an alternative method of producing a cheap source of protein rich food since sorghum is a low-cost cereal and good energy source while pigeon pea contains essential protein necessary for health growth and maintenance (de Pee and Bloem, 2009). Hence such complementary products can reduce the problems caused by under nutrition.

Despite the nutritional benefits from complementing sorghum with pigeon peas, extrusion cooking offers additional advantages such as starch gelatinization, protein

denaturation, inactivation of anti-nutritional factors, destruction of microorganisms. Therefore the extrudates can be stored for long periods without being refrigerated (Filli *et al.*, 2010).

#### **1.4 Extrusion and Extrusion Cooking**

Extrusion cooking is a modern high-temperature short-time (HTST) processing technology, which is becoming popular in food industries because it offers several advantages over other types of cooking processes. The advantages include faster processing time and significant reduction in energy consumed, which consequently result in lower prices for the final products (Branèiæ *et al.*, 2006). The products of extrusion are important in the food and feed industries (Byaruhanga *et al.*, 2014).

An extruder represents a very complex bioreactor in which, various types of food raw materials with different moisture contents and viscosities are treated, under high temperatures, short residence times, high pressures and very strong shear forces (Branèiæ *et al.*, 2006). This is achieved by forcing the material through a tapering screw shaft and passing through a die plate under high pressure accompanied by an injection of steam or water.

During processing through the extruder, a dough-like mixture is forced through a stationary metal tube or barrel by a rotating screw shaft (Nurtama and Lin, 2009). As this occurs, heat can be added in the form of steam and generated by the mechanical energy of the turning screw and the friction of the barrel.

In extrusion cooking starch is gelatinized and protein is denatured, which improves their digestibility (Singh *et al.*, 2007). Anti-nutritional factors that are inactivated,

microorganisms are destroyed and the product's shelf-life is thereby extended (Singh *et al.*, 2007). Extrudates become microbiologically safe and can be stored for long periods because of low moisture without need for refrigeration (Filli and Nkama, 2007).

Food industries apply extrusion technology to produce various products such as pasta, ready to eat cereals, meat analogs, flat bread and puffed snacks (Nurtama and Lin, 2009). Starchy materials from different kinds of cereals, legumes and tubers are commonly used in extrusion process (Nurtama and Lin, 2009).

The extrudates formed has characteristic properties that are very different from the starting raw materials (Cai *et al.*, 1995). The use of extruders for food cooking has been expanding rapidly in the food industry due to their versatility, high productivity, efficiency, hygiene conditions and low operation cost (Riaz, 2000).

In the United States of America, sorghum is mostly used for feed; however studies have been done to evaluate the importance of sorghum and its extrudates for food. Nanubala *et al.* (2013) and Joseph *et al.* (2016) are some authors that undertook studies on sorghum blended foods including snacks; they suggested the importance of extrudates on sorghum on management of protein energy malnutrition especially for the infants.

In Southern Africa, research on the utilization of sorghum and its processing techniques has been actively pursued. Different studies have been done to evaluate the extrudates nutritional characteristics and acceptance by the consumers. Dlamini (2017), Pelembe *et al.* (2002), and Yusuf *et al.* (2018) are few studies on sorghum extrudates. From their studies, they found that extrusion cooking improves the nutritional quality and appealing of the products such as snacks and flour which drives the consumer preferences.

Employment of processing techniques such as malting and fermentation increase the diversification of the sorghum by products.

### **1.5 Problem statement and Justification**

Sorghum is an important food security grain in drought-prone areas (Pelembé *et al.*, 2002). It is locally available and easily accessed by most of the families as it is a cheap source of starch (Awika and Rooney, 2004).

Traditionally, sorghum is used to make meals such as stiff porridge, porridge especially for infants and young children. These meals are characterized by poor protein quality, low energy, low nutrients density, and takes long preparation time (Afoakwa *et al.*, 2004). They are poorly processed and highly contaminated with microbes (Mugula *et al.*, 2011). The consumption of poor nutrients and contaminated meals in long run could result in under nutritional diseases and probably death (de Pee and Bloem, 2009).

Complementing the starchy based meals with legumes is among the approach that increases sorghum utilization and dietetic management of the diseases caused by poor, unsafe diets to the infants and young children (Devi *et al.*, 2013). This is because cereals and legumes are locally available and constitute a well-balanced diet in-combination which is crucial in improving children health (Ijarotimi and Keshinro, 2013).

The instant products saves food preparations time as compared to normal cooking, because the extrudates are ready-to-eat and do not involve further time taking preparations such as boiling and stirring of porridge for some time when preparing porridge. The saved time especially for lactating mothers can help them to engage in other economic activities which can boost their families earning and diet.

Therefore this study aimed at developing instant porridge flour for infants and young children by complementing varieties of white sorghum and pigeon peas and evaluation of nutritional, physical and sensory quality of extruded instant whole white sorghum-pigeon peas flour.

## **1.6 Objectives**

### **1.6.1 Overall objective**

The overall objective of the study was to develop nutritious and acceptable sorghum-pigeon peas instant porridge flour.

### **1.6.2 Specific objectives**

The specific objectives of this study were to:

- i. determine the physical properties including the bulk density, water absorption index, water solubility index and viscosity of extruded white sorghum varieties complemented with pigeon peas.
- ii. determine the chemical quality including proximate, mineral composition and protein digestibility of extruded white sorghum varieties complemented with pigeon peas.
- iii. evaluate the acceptability of the instant gruel prepared from white sorghum varieties complemented with pigeon peas.

### **1.6.3 List of manuscripts**

- i. Physical and sensory quality of sorghum-pigeon peas instant porridge flour.
- ii. Nutritional quality of sorghum-pigeon peas instant porridge flour.

The findings of this research were reported in two manuscripts presented chapter two and three.

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## CHAPTER TWO

### 2.0 Physical and Sensory Quality of Sorghum-Pigeon Peas Instant Porridge Flour

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#### 2.1 Abstract

Five varieties of white sorghum consumed in Tanzania namely, *Pato, Hakika, Tegemeo, Macia* and *Wahi*, non-complemented and complemented with pigeon peas at ratios 75:25, 70:30 then extruded to produce instant flour. The physical and sensory parameters of the instant flour were evaluated. The bulk density was 0.5-0.7 gcm<sup>-3</sup>, viscosity 0.5-0.8 dpas, water absorption index 0.04-0.6 g/g, water solubility index 24.1-41.2%. As pigeon peas were added in sorghum varieties, there was an increase in bulk density, viscosity and water solubility index, while the water absorption index decreased. The instant porridge was prepared and sensory evaluated. The formulations were accepted based on the attributes flavor, aroma, taste, viscosity and colour. Therefore, pigeon peas improved the physical and sensory quality of white sorghum instant porridge flour.

#### 2.2 Introduction

Physical properties of extrudates depend on many factors including the macromolecules in the food matrix such as protein and the amount of these molecules that is present (Guy, 2001). The Water solubility index and Water absorption index gives an indication of the changes in starch occurred in processing (Muller, 2016). Bulk density and viscosity of the flour determines how viscous the gruel shall be prior to sensory evaluation test. The knowledge of these physical properties is important when

considering packaging, storage of extrudates, transportation of extrudates and consumer preferences.

Food sensory evaluation can be defined as the analysis and interpretation of the identified and measured food product properties (Meilgaard *et al.*, 2006). Human subjects are used because they are the consumers of the products; they have the ability to discriminate the difference between products; can describe characteristics that are found between products; and can indicate the preferences, liking or acceptability of products (Mongi, 2015). Through sensory evaluation, the food products quality can be evaluated or improved. This evaluation can provide inputs for decision making and product development, determine the market value of products, determine the shelf-life of products, determine ingredient substitution in product formulation, assist to compare products with the competitor's products, and determine storage conditions of the products (Anton *et al.*, 2009).

Consumer acceptance of extruded foods is mainly due to the convenience, value, attractive appearance and smoothness which are found to be particular for these foods, especially gruel flour products (Anton *et al.*, 2009). Extruded foods have been proven to provide nutritious products and combine quality ingredients and nutrients to produce processed foods that contain precise levels of each required nutrient (Yagci and Gogus, 2008). Therefore this study aimed at determining the physical and sensory quality of sorghum-pigeon peas instant porridge flour which are crucial in commercialization of sorghum products.

## **2.3 Materials and Methods**

### **2.3.1 Samples**

White sorghum varieties namely *Macia*, *Tegemeo*, *Pato*, *Wahi* and *Hakika*, and Pigeon peas were purchased from Ilonga Research Institute, Kilosa district in Morogoro region, Tanzania.

## **2.3.2 Sample preparation**

### **2.3.2.1 Sorting and cleaning**

White sorghum and pigeon peas were sorted to remove extraneous matter and damaged grains, then washed to remove dust and mud.

### **2.3.2.2 Drying**

The samples were dried overnight in an oven at 65°C according to the procedure described by Oyetoro *et al.* (2012).

### **2.3.2.3 Milling**

The whole white sorghum and pigeon peas samples were milled into fine flour (sieve size-1mm) using a commercial hammer mill (Mzinga corporation, morogoro, Tanzania). From each white sorghum variety flour a sample was taken and stored in polyethylene packets to be used as a control in studying the contribution of extrusion process and pigeon pea blend on nutritional quality and acceptability of the white sorghum varieties. The remained samples were used to make the sorghum-pigeon pea blend formulations.

### **2.3.2.4 Sample formulation and composition**

The samples were combined in proportions that provided the highest amino acid score (>65%) proportions that meet the FAO/WHO/UNU (1985) requirements for energy and essential amino acids for young children and infants. Fifteen samples of instant gruel flour were formulated, as indicated in Table 2.1. Therefore a total of 20 gruel flour samples were prepared (including 5 control samples from each white sorghum variety).

**Table 2.1: Composition of the sorghum-pigeon peas based complementary food formulations (g/100 g)**

<b>Sorghum variety</b>		<b>Pigeon peas</b>	<b>Total</b>
<i>Macia</i>	100	0	100
	75	25	100
	70	30	100
<i>Pato</i>	100	0	100
	75	25	100
	70	30	100
<i>Hakika</i>	100	0	100
	75	25	100
	70	30	100
<i>Tegemeo</i>	100	0	100
	75	25	100
	70	30	100
<i>Wahi</i>	100	0	100
	75	25	100
	70	30	100

### **2.3.3 Extrusion cooking process**

Extrusion of the composite flours was carried out in a commercial twin-screw extruder (Kneader Model EX 60, Chaoyuan Power Machinery. Co. Ltd, China). Prior to extrusion, 15 sorghum-pigeon pea samples were conditioned by thoroughly mixing with potable water to a moisture content of 26% for easy cooking process. For all the formulations, the following extrusion conditions were adopted: Temperatures for zone 1 and zone 2 were 136°C and 113°C, respectively. The main motor speed was set at 37.5 rpm and feeder speed at 18.5 rpm. After extrusion, the extrudates were allowed to dry at room temperature and thereafter milled (sieve size- 1mm) to obtain extruded flour. Extruded flour was packaged in polyethylene packets and kept at room temperature for analyses.

## 2.3.4 Analyses

### 2.3.4.1 Bulk density

Bulk density (BD) of the samples was determined according to the procedure described by Stojceska *et al.* (2008). The bulk density of the samples was calculated by taking the ratio of sample weight in a cylinder to its volume.

Bulk Density was calculated using formula:

$$BD (g/cm^3) = \frac{\text{Weight of cylinder and sample} - \text{weight of empty cylinder}}{\text{volume of sample in the cylinder}} \dots(\text{viii})$$

### 2.3.4.2 Viscosity

HAACE Viscotester 2plus (Thermo-electron company, Karlsruhe, Germany) was used to determine the viscosity of the porridge. Samples of porridge in duplicate were prepared for the test and 100 mL of each porridge sample were used for determination of viscosity. The 3 and 2 rotary numbers were used (Thermo-electron Company, 2011).

### 2.3.4.3 Water Absorption Index (WAI) and Water Solubility Index (WSI)

The water absorption index and water solubility index were determined by using the method for cereals described by Anderson (1969). The extrudates samples were sieved into fine flour with particle size 250  $\mu$ m. One gram of each sample was suspended in 10 mL of distilled water at room temperature (approximately 28°C) and gently stirred for 40 min then centrifuged at 3000 rpm for 10 min. The supernatant was decanted into an evaporation dish of known weight. The water absorption index was the weight of gel obtained after removal of the supernatant per unit weight of original dry solids. The supernatant was then dried in an oven at 105°C over-night, the weight of dried supernatant was then recorded.

The water solubility index was the weight of dry solids in the supernatant expressed as a percentage of the original weight of sample.

Water absorption index and water solubility index were calculated using the following formulae:

$$WAI(g/g) = \frac{\text{weight of wet gel}}{\text{weight of the sample}} \dots\dots\dots(\text{ix})$$

$$WSI(\%) = \frac{\text{weight of dry solid in the supernatant}}{\text{weight of the sample}} \times 100 \dots\dots\dots(\text{x})$$

### **2.3.5 Preparation for and sensory evaluation**

#### **2.3.5.1 Training**

To conduct quantitative descriptive test, eight panelists were trained for three days, the attributes and intensities to be used were discussed and agreed. The pre-test was conducted to assess the trainees understanding before the actual test.

#### **2.3.5.2 Gruel preparations**

The gruel were prepared using flour, sugar, hot water then kept in the oven at 45<sup>0</sup>C ready for evaluation.

### **2.3.6 Sensory evaluation**

The sensory evaluation test was categorized in quantitative descriptive test and consumer test (Meilgaard *et al.*, 2006). In quantitative descriptive test eight trained panelists (four males and four females) were subjected to twenty prepared coded gruel samples at once to assess the intensity of attributes colour, aroma, viscosity, taste, mouth feel, uniformity using a 9-point scale.

In Consumer test a 7-point scale which rates as follows 7 (like very much), 6 (like moderately), 5 (like slightly), 4 (neither like nor dislike), 3 (dislike slightly), 2 (dislike moderately), and 1 (dislike very much) were used (Meilgaard *et al.*, 2006). Thirty panelists were subjected to prepared porridge samples to assess and give scores for the attributes; colour, aroma, taste, and overall acceptability. Twenty coded gruel samples in cups were presented in three sessions: 7, 7, and 6 samples for first, second and third session, respectively in difference of 10 minutes. The following were the characteristics of the panelists subjected to consumer test.

**Table 2.2 Characteristics of the consumers panel (n=30)**

<b>Characteristics</b>	<b>Category</b>	<b>Frequency (N)</b>	<b>Percent (%)</b>
Age	19-30	29	96.7
	31-40	1	3.3
	<b>Total</b>	<b>30</b>	<b>100</b>
Gender	Male	14	46.67
	Female	16	53.33
	<b>Total</b>	<b>30</b>	<b>100</b>

The gruel preparations and sensory evaluation tests were conducted in the laboratories of the Department of Food Technology, Nutrition and Consumer Sciences at Sokoine University of Agriculture. The Bachelor and Master's degree students at SUA were the panelists.

### **2.3.7 Statistical analysis**

The design of the experiment was factorial design with two factors under consideration: white sorghum varieties and pigeon pea levels. The results were presented as an average of two replicates. Physical parameters were analyzed by SPSS while the Sensory

evaluation data were analyzed by two way ANOVA using R COMMANDER software program, Duncan's Multiple Range Test method were used to assess the difference between means at 95% confidence interval .

## 2.4 Results and Discussion

The physical properties of fifteen sorghum-pigeon peas based extrudates are shown in Table 2.3. Generally it was observed that upon extrusion and addition of pigeon peas the physical properties of extrudates increased significantly except for water absorption index.

**Table 2.3: Physical characteristics of sorghum-pigeon peas instant porridge flour**

Sample	Bulk density (g/cm <sup>3</sup> )	Viscosity (dipas)	Water absorption index (g/g)	Water solubility index (%)
<i>Pato</i> sorghum	0.6±0.0 <sup>abcd</sup>	0.5±0.1 <sup>a</sup>	0.5±0.0 <sup>h</sup>	35.2±0.1 <sup>cd</sup>
<i>Pato</i> -pigeon peas (75:25)	0.6±0.0 <sup>bcd</sup>	0.5±0.1 <sup>ab</sup>	0.2±0.0 <sup>de</sup>	38.6±2.8 <sup>ef</sup>
<i>Pato</i> -pigeon peas (70:30)	0.6±0.0 <sup>bcd</sup>	0.6±0.3 <sup>cd</sup>	0.1±0.0 <sup>b</sup>	34.9±1.4 <sup>cd</sup>
<i>Wahi</i> sorghum	0.6±0.0 <sup>de</sup>	0.6±0.1 <sup>ab</sup>	0.5±0.0 <sup>h</sup>	24.1±0.2 <sup>a</sup>
<i>Wahi</i> -pigeon peas (75:25)	0.7±0.0 <sup>g</sup>	0.7±0.1 <sup>abcd</sup>	0.2±0.0 <sup>cd</sup>	29.8±0.3 <sup>b</sup>
<i>Wahi</i> -pigeon peas (70:30)	0.6±0.0 <sup>bcd</sup>	0.8±0.0 <sup>d</sup>	0.2±0.0 <sup>de</sup>	36.6±0.6 <sup>de</sup>
<i>Hakika</i> sorghum	0.5±0.0 <sup>abc</sup>	0.6±0.1 <sup>ab</sup>	0.6±0.0 <sup>i</sup>	34.3±0.2 <sup>c</sup>
<i>Hakika</i> -pigeon peas (75:25)	0.6±0.0 <sup>ef</sup>	0.8±0.1 <sup>e</sup>	0.2±0.0 <sup>cd</sup>	35.4±1.1 <sup>cd</sup>
<i>Hakika</i> -pigeon peas (70:30)	0.6±0.0 <sup>de</sup>	0.8±0.1 <sup>d</sup>	0.04±0.01 <sup>a</sup>	28.7±0.3 <sup>b</sup>
<i>Tegemeo</i> sorghum	0.5±0.0 <sup>a</sup>	0.6±0.0 <sup>abc</sup>	0.4±0.0 <sup>g</sup>	25.9±0.7 <sup>a</sup>
<i>Tegemeo</i> -pigeon peas (75:25)	0.6±0.0 <sup>abcde</sup>	0.6±0.0 <sup>abcd</sup>	0.3±0.0 <sup>ef</sup>	39.2±0.6 <sup>fg</sup>
<i>Tegemeo</i> -pigeon peas (70:30)	0.7±0.1 <sup>fg</sup>	0.7±0.0 <sup>abcd</sup>	0.2±0.0 <sup>c</sup>	38.0±0.1 <sup>ef</sup>
<i>Macia</i> sorghum	0.5±0.0 <sup>ab</sup>	0.7±0.1 <sup>abcd</sup>	0.3±0.0 <sup>f</sup>	28.2±0.1 <sup>b</sup>
<i>Macia</i> -pigeon peas (75:25)	0.6±0.0 <sup>bcd</sup>	0.5±0.0 <sup>a</sup>	0.1±0.0 <sup>b</sup>	38.7±0.7 <sup>ef</sup>
<i>Macia</i> -pigeon peas (70:30)	0.6±0.0 <sup>cde</sup>	0.8±0.0 <sup>abcd</sup>	0.1±0.0 <sup>b</sup>	41.2±0.9 <sup>g</sup>

Values are expressed as mean± standard deviation (n=2) on dry basis. Mean values with different super script letters along the column are significantly different at p≤0.05.

### 2.4.1 Bulk density

The bulk density is a function of particle size as particle size is inversely proportional to bulk density (Onimawo and Akubor, 2012). It has been reported that bulk density is influenced by the structure of the starch polymers; loose structure of the starch polymers could result in low bulk density (Malomo *et al.*, 2012). From the study, the bulk density ranged from 0.5 gcm<sup>-3</sup> in *Tegemeo* sorghum to 0.7 gcm<sup>-3</sup> in *Wahi-pigeon* peas (75:25).

The bulk density increased as quantity of sorghum was reduced while pigeon peas were added to all white sorghum varieties formulations.

Similar trend of increasing bulk density was reported in sorghum extrudates containing increasing amounts of cowpea flour (Pelembé *et al.*, 2002). The study by Rampersad *et al.* (2003) reported that on increasing additions of pigeon pea flour to cassava flour, expansion of extrudates decreased, while product bulk density increased. Low bulk density of flour is a good physical attribute when determining transportation and storability while high bulk density is desirable for greater ease dispersibility and reduction of paste thickness (Amandikwa, 2012). Nutritionally, low bulk density promotes easy digestibility of food products, particularly among children with immature digestive system (Osundahunsi and Aworh, 2002).

### 2.4.2 Viscosity

The viscosity of the samples under this study was from 0.5 dpas in extruded *Pato* sorghum variety sample to 0.8 dpas in *Wahi-pigeon* peas (70:30). It was noted in all white sorghum varieties that as pigeon peas were added and sorghum were reduced, the viscosity increased. This increase in viscosity especially to the sorghum-pigeon peas porridge flour is important for children as it aid digestion. This is because of the breakdown of starch components to smaller particles that are easily absorbed hence

digested. Low viscosity is much preferred for extruded porridge since it enables intake of nutrient-dense food during consumption.

### **2.4.3 Water absorbing index**

The water absorption index measures the volume occupied by the starch polymer or granule after swelling in excess water and can be used as an index of gelatinization (Ijarotimi and Ashipa, 2005). It gives information about the easier in which the mixture absorb water and therefore pre-determines the storage methods where the air tight package is encouraged to avoid moisture pick up of the products. A high water absorption index is a desirable property in ready-to-eat porridges (Pelembé *et al.*, 2002).

The study observed the range of 0.04 g/g in *Hakika*-pigeon peas (70:30) to 0.6 g/g in *Hakika* sorghum. Upon extrusion the water absorption index increased but decreased as pigeon peas were added to sorghum to form composite flour. Low water absorption index is favored during storage as it reduces microorganism attack of food that causes spoilage of diets (Malomo *et al.*, 2012). Byaruhanga *et al.* (2014) reported that the extrudates had water absorption index 2-3 times higher than the control un-extruded flour, which had a decreased of water absorption index of extrudates.

The study by Arun Kumar *et al.* (2015) found that the water absorption index decreased significantly ( $P < 0.01$ ) as soy level increased in sorghum mainly because of reduction in the starch content. Relative decrease in starch content with addition of soya may affect the extent of starch gelatinization in barrel and caused reduced water absorption. Similar effects of adding non-starch components on water absorption index have been reported earlier for millet-legume blend (Subir *et al.*, 2011). The study by Rampersad *et al.* (2003) reported that upon increasing of pigeon peas flour to cassava flour resulted in higher water absorption index and lower water solubility index of extrudates ( $p < 0.01$ ).

#### **2.4.4 Water solubility index**

Water solubility index determines the amount of soluble components released from the starch after extrusion and often used as a parameter that indicates the degradation by starch granules (Ijarotimi and Ashipa, 2005). It measures the amount of soluble polysaccharide released from the starch component after extrusion (Ding *et al.*, 2005).

The water solubility index ranged from 24.1% in *Wahi* sorghum sample to 41.2% in *Macia*-pigeon peas (70:30). As pigeon peas were added in the formulation, the gradual increase in water solubility index was observed in all sorghum varieties possibly due to the dextrinisation and de-polymerisation of starch at extrusion temperatures, reducing molecular weight of amylose and amylopectin chains (Malomo *et al.*, 2012). Pelembe *et al.* (2002) found water solubility index increased as the percentage of cowpeas increased for both extrusion temperatures, due to water-soluble components, like proteins, which are present in cowpeas. Byaruhanga *et al.* (2014) reported that the extrudates had water solubility index 2-3 times higher than the control un-extruded flour. A high water solubility index is favorable as it helps digestion especially for young children and infants whose digestive system is still immature (Subir *et al.*, 2011).

#### **2.4.5 Sensory evaluation**

In assessing the products acceptability by the panelists who are consumers of the products, it is important to get general information about the characteristics of the consumer. The characteristics of the panelists that conducted sensory test are as shown in Table 2.4

**Table 2.4: Characteristics of the test panel used in evaluation of sorghum-pigeon peas instant porridge (n=30)**

<b>Characteristics</b>	<b>Category</b>	<b>Frequency (N)</b>	<b>Percent (%)</b>
Frequency of consumption	Daily	4	13.3
	Once per week	9	30
	Once per month	11	36.7
	Seldom	6	20
	<b>Total</b>	<b>30</b>	<b>100</b>
Brand preferred	<i>Macia</i> sorghum	10	37.0
	<i>Hakika</i> -pigeo peas (75:25)	7	24.1
	<i>Pato</i> sorghum	7	24.1
	<i>Macia</i> sorghum (milled)	7	25.9
	<i>Pato</i> sorghum (milled)	7	25
	<i>Wahi</i> sorghum (milled)	7	25

From the results above, it was observed that majority of the panelists were users of the product under study. They were familiar with the attributes of the products; hence increase the reliability of the sample scores. The instant porridges samples were more preferred by the panelists than the control porridge samples.

#### **2.4.6 Sensory attributes**

Table 2.5 shows the acceptability of sorghum-pigeon pea instant porridge; It was observed that the aroma, taste, general acceptability were not significantly different in all sorghum-pigeon peas instant porridges; while the colour of the instant porridge was significantly different in all white sorghum varieties.

##### **2.4.6.1 Aroma**

There was no a significant difference in aroma that was contributed by white sorghum varieties and the combination of sorghum and pigeon peas. These results were similar to Dlamini (2017) report that found no significant difference in aroma on extruded snacks

made by combination of sorghum and cowpeas. It could be attributed by the release of aroma compounds with the steam when extrudates are forced out of the die. The aroma refers to the product smell. The aroma of food product influences the preference of that product, as it affects acceptability. The good smell attracts acceptance of the products.

**Table 2.5: Acceptability of sorghum-pigeon peas instant porridge**

Sample	Aroma	Colour	Taste	General acceptability
<i>Pato</i> sorghum (milled)	4.8±1.3	5.1±1.3 <sup>e</sup>	5.0 ±1.1	5.0±1.2
<i>Pato</i> sorghum	5.5±0.8	4.4±1.5 <sup>t</sup>	5.4 ± 1.1	5.3± 1.1
<i>Pato</i> -pigeon peas (75:25)	4.9±0.9	5.0±0.9 <sup>j</sup>	4.8 ±1.0	4.8 ±0.7
<i>Pato</i> -pigeon peas (70:30)	5.0±1.1	4.9±1.0 <sup>m</sup>	4.6 ± 1.0	4.8 ±0.9
<i>Wahi</i> sorghum (milled)	4.8±1.2	5.3±1.2 <sup>a</sup>	4.8 ± 1.3	4.8 ±0.9
<i>Wahi</i> sorghum	5.1±0.9	5.2±1.0 <sup>c</sup>	5.2 ±1.2	5.2 ±0.9
<i>Wahi</i> -pigeon peas (75:25)	4.8±1.1	5.1±1.1 <sup>i</sup>	4.8 ±1.0	4.7± 0.9
<i>Wahi</i> -pigeon peas (70:30)	5.0±0.9	4.9±0.9 <sup>l</sup>	4.6±1.0	5.0 ±0.9
<i>Hakika</i> sorghum (milled)	4.9±1.5	5.1±1.2 <sup>g</sup>	4.5 ±1.1	4.8 ±1.3
<i>Hakika</i> sorghum	5.2±0.8	4.5±0.9 <sup>s</sup>	4.8 ± 1.1	5.0±0.7
<i>Hakika</i> -pigeon peas (75:25)	5.3±0.9	5.1±0.9 <sup>f</sup>	5.2 ± 1.3	5.4± 1.1
<i>Hakika</i> -pigeon peas (70:30)	5.0±1.1	4.8±0.9 <sup>p</sup>	4.7 ± 1.1	4.8± 0.9
<i>Tegemeo</i> sorghum (milled)	4.6±1.2	5.3±1.1 <sup>b</sup>	4.5 ± 1.1	4.8± 1.1
<i>Tegemeo</i> sorghum	4.8±0.9	5.0±0.9 <sup>k</sup>	4.9 ± 0.9	5.1 ±0.9
<i>Tegemeo</i> -pigeon peas (75:25)	4.9±1.0	4.6±1.1 <sup>q</sup>	4.7 ± 1.1	4.9±0.9
<i>Tegemeo</i> -pigeon peas (70:30)	4.7±0.9	5.2±1.0 <sup>d</sup>	4.7 ±0.9	4.8± 0.9
<i>Macia</i> sorghum (milled)	4.9±1.4	5.1±1.2 <sup>h</sup>	4.9 ±1.3	5.1± 1.3
<i>Macia</i> sorghum	5.0±0.9	4.9±1.1 <sup>n</sup>	5.1 ± 1.3	5.2± 1.2
<i>Macia</i> -pigeon peas (75:25)	4.9±1.1	4.8±1.1 <sup>o</sup>	5.1 ±0.9	5.1± 0.9
<i>Macia</i> -pigeon peas (70:30)	4.6±1.1	4.5±1.2 <sup>r</sup>	4.3 ±1.2	4.7± 0.9

Values are expressed as mean± standard deviation (n=30). Mean values with different super script letters along the column are significantly different at  $p \leq 0.05$ .

#### 2.4.6.2 Colour

It was observed that there was a significant difference in colour for all the samples under study. This difference was influenced by difference in intensity of whiteness among the white sorghum varieties, the combination with pigeon peas which were pale yellow contributed to the difference in colour. This variation led to different score of the

samples colour. Dlamini (2017), found the difference in colour of extruded snacks made by combination of sorghum and cowpeas. The study by Tufa *et al.* (2016) reported differences in colour between the control plain sorghum flour and a composite of sorghum and cowpea. Rampersad *et al.* (2003) reported that on increasing additions of pigeon pea flour to cassava flour, the extrudates became more yellow.

Colour is among the attributes that lead to product liking and acceptability. It influences the consumer toward that product, although the consumers differ in colour preferences, but overall the product colour highly influences the sale of that product. The consumers always look for the resemblance between the new products with the previous experience they have about those types of products. Therefore, variation from their experience may result in much product acceptance or rejection of the product. That's why it is important to consider this fact when developing new products.

#### **2.4.6.3 Taste**

Taste is an attribute that surpasses other attributes in food products. This is because most food products are defined by their taste. The food product may be superior in other attributes such as colour, smoothness and viscosity but poor taste negatively affects the product. The product taste can be expressed in its saltiness, sweetness, sourness, and bitterness. The taste of porridge samples under study was much influenced by the amount of sugar added. Too much or too little sugar affects the product taste.

It was observed that there was no a significant difference in the taste of the porridge samples which means the products tested more likely the same. This was because of similarity in sugar, flour and water that were used as a recipe. The difference in sorghum varieties and the pigeon peas added did not bring any significant difference on the

porridge taste according to the consumers score. Ognean (2015) found that the smell and taste of breads with sorghum remained pleasant even at 40% replacement of wheat flour.

#### **2.4.6.4 General acceptability**

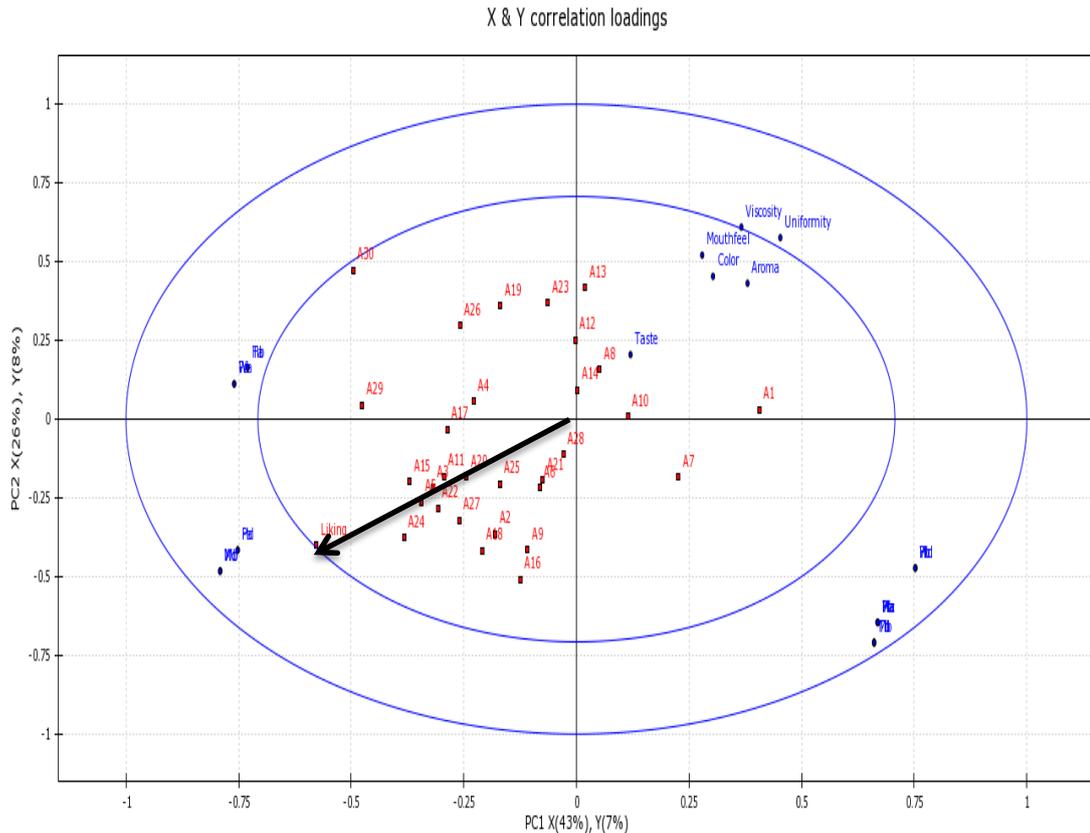
The score of samples attributes contributes to the general acceptability of the whole product. The general acceptability had the highest mean compared to other attributes, which means the panelists positively responded to the porridge products displayed. It was observed that there was no significant difference in general acceptability of the different samples under study. This indicates no intense variation observed on the panelist acceptability of the products. It can be expressed that any of the white sorghum variety can be used in substitute for porridge flour development and it would not affect the acceptability of such products. The acceptability score predicts the products performance in the market since the consumers show the willingness of buying the product.

#### **2.4.7 Preference mapping**

In preference mapping, the correlation of the panelists, samples, and the attributes can be studied. This technique explains the variation in samples and the associated attributes; and the drivers that influenced the correlation of the panelist preferences.

#### **Relationship between consumer data and quantitative descriptive data by Partial Least Square Regression (PLSR) for students**

This method combines the hedonic test scores and quantitative descriptive scores to give the attributes that influenced the product brands preference by the panelists which is crucial in product development. It shows the results from a PLSR using descriptive data as X variables and liking by students as Y-variables.



**Figure 2.1: Correlation loadings from a partial least squares regression of porridge samples with descriptive data as X variables and hedonic rating by students as Y variables.**

From Figure 2.1, the principal component (PC1) is the contrast between samples in Left Hand Side and those in Right Hand Side of the figure while the PC2 is the contrast between the top and bottom samples of the figure. The PC1 explain 43% variation in Quantitative data (X) and 7% variation in consumer liking (Y) while the PC2 explain 26% variation in Quantitative data (X) and 8% variation in consumer liking (Y).

Figure 2.1 shows that most panelists were on the product liking side, indicating that the samples were liked by the panelists: It show the associated attributes that led to liking of the products which were taste, aroma, mouth feel, uniformity, colour and least by viscosity. Further-more it shows that samples were on the liking side indicating that panelists accepted the products under study.

## **2.5 Conclusion**

The study showed that for the product to be accepted by the consumer, both physical and sensory qualities should be considered. The consumer relies on the physical qualities to judge the general quality of the product. It was observed that aroma, taste, mouth feel, uniformity attributes influenced the acceptance of instant porridge. Therefore, during food product development the physical parameters must be considered since they reflect consumer acceptability and reflect the storage conditions.

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## CHAPTER THREE

### 3.0 Nutritional Quality of Sorghum- pigeon Peas instant Porridge Flour

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#### **3.1 Abstract**

Five varieties of white sorghum consumed in Tanzania namely *Pato, Hakika, Tegemeo, Macia* and *Wahi*; non-complemented and complemented with pigeon peas at ratios 75:25, 70:30 were extruded to produce instant porridge flour. The nutritional composition of the flour was evaluated; crude fibre 3.6-8.9 g/100 g dry matter (DM), crude fat 0.5-3.6 g/100 g DM, ash 0.6-2.6 g/100 g DM, crude protein 9.5-14.1 g/100 g DM, carbohydrates 67.7-83.8 g/100 g DM, energy 323-397 kcal. The content of calcium, magnesium, potassium, copper, zinc and iron was 268.2-395.6, 243.2-336.2, 370.1-915.2, 0.1-0.4, 1.9-3.8 and 3.1-8.5 mg/100 g DM, respectively. The digestibility was 7.4-11.8 g/100 g DM. Therefore the inclusion of pigeon peas and the extrusion cooking contributed to the improved nutritional quality and digestibility of the white sorghum instant porridge flour for young children and infants.

#### **3.2 Introduction**

For a healthy growth, children must be provided with nutritious food rich in vitamins, minerals, proteins and carbohydrates. These are crucial to the infants and young children for normal growth and management of the diseases caused by poor diet including malnutrition, which has long been known as a major nutritional problem in developing

countries (FAO *et al.*, 2015). After six months when breast milk alone is no longer sufficient to meet all nutritional requirements, it is the time to introduce complementary foods, i.e. foods that are readily consumed and digested by the young child and that provide additional nutrition to meet all the growing child's needs. FAO *et al.* (2015) reported that lack of quantity and quality complementary foods, poor child-feeding practices, and high rates of infections, contribute to health and growth impairments in the recent years.

Traditional complementary foods in Tanzania are based on starchy staples, usually cereals such as maize, rice, sorghum and finger millet and non-cereals such as cassava, sweet potatoes, yams, bananas and plantains (Mosha *et al.*, 2000). Such foods are usually supplied without adequate supplementation with high quality protein sources (Kikafunda *et al.*, 2006). These foods are commonly available, cheap and hence affordable to mostly people living in rural areas but are lysine deficient (FAO *et al.*, 2015). Over dependency of these starchy sources as protein sources is the main cause for the widespread protein-energy malnutrition to infants and young children.

On the other hand legumes are nutritionally important because of their relatively high protein content. They are widely available and provide a richer source of protein especially lysine than cereals (Ofuya and Akhidue, 2006). The use of such inexpensive, high protein sources is highly recommended for combating protein-energy deficiency diseases and to improve the nutritional status in developing countries (Shiriki *et al.*, 2015).

Combination of common cereals, which are deficient in lysine but have sufficient amount of sulphur-containing amino acids, with inexpensive plant protein sources like

legumes that are rich in lysine can be used to improve the nutritive value of cereal food products that meet the nutritional requirements of the infants and young children (Hamid *et al.*, 2016).

### **3.3 Materials and Methods**

#### **3.3.1 Samples**

White sorghum varieties namely *Macia*, *Tegemeo*, *Pato*, *Wahi* and *Hakika*, and Pigeon peas were purchased from Ilonga Research Institute, Kilosa district in Morogoro region, Tanzania.

#### **3.3.2 Proximate and mineral composition**

The proximate composition including dry matter, crude protein, crude fibre, crude fat and ash of the extruded and un-extruded product were determined according to official AOAC (1999). The results were presented as an average of duplicate determinations.

##### **3.3.2.1 Crude fat**

Total fat was determined by using Soxhlet ether extraction official method 945.87 (AOAC, 1999). The dry sample (5 g) was placed into the extraction thimble and assembled to the soxhtec apparatus. The petroleum ether 60 mL of was used for continuous reflux for 55 min in three phases, the boiling phase for 15 min, the fat extraction phase for 30 min and petroleum ether recovery phase for 10 min. Petroleum ether was then recovered by evaporation. Pre-weighed cups containing fat were dried in an oven at 105°C for 30 min to evaporate any remaining petroleum ether, cooled in a desiccator for 20 min and weighed.

Percentage fat was calculated by using the formula:

$$\% \text{ Crude fat} = \frac{\text{Weight of crude fat (g)}}{\text{Weight of dry sample (g)}} \times 100 \dots\dots\dots(v)$$

### 3.3.2.2 Ash content

Ash content was determined according to AOAC (1999), method 923.03. Five grams of dry sample was oven dried at 105°C for 24 h. The weight of crucible and dried sample were recorded. The dried samples in crucibles were incinerated in a muffle furnace at 550°C for 3 h, grey ash was obtained. Ash content was calculated as the difference between the weight of sample before and after incineration

Percentage ash was calculated from the relationship:

$$\text{Ash}(\%DM) = \frac{\text{weight of ash (g)}}{\text{weight of dry sample (g)}} \times 100 \dots\dots\dots(i)$$

### 3.3.2.3 Crude protein

Crude protein content of the samples was determined using the micro-Kjeldahl method 920.87 (AOAC, 1999). The dried sample 0.5 g were weighed and transferred into digestion tubes; 0.6 g of catalyst (mixture of 10 g K<sub>2</sub>SO<sub>4</sub>, 0.5 g CuSO<sub>4</sub>), 6 mL of concentrated H<sub>2</sub>SO<sub>4</sub> were added to each tube. Samples were digested using Tecator digestion system 40 (Model 1016 digester, Sweden) for 3 hr to obtain a clear greenish solution. The digest was cooled and mounted in the distillation unit (Foss Tecator, Model 2200 Kjeltex auto distilling unit, Sweden). The distilled water, 70 mL was added to the digest followed by 70 mL of 40% NaOH and steam distilled for 4 min. The distillate, 50 mL was collected in conical Erlenmeyer flask containing 25 mL of 4% boric acid. The distillate was thereafter titrated with 0.105 g/100 mL hydrochloric acid. The blank volume was carried out and 0.04 mL obtained.

$$\% \text{ Nitrogen} = \frac{14.01 \times (\text{titre} - \text{blank}) \text{ mL} \times \text{concentration of acid in n/mol}}{\text{weight of sample (g)} \times 10} \times 100 \dots\dots(ii)$$

$$\% CP = \%Nitrogen \times 6.25 \dots\dots\dots(iii)$$

### 3.3.2.3 Crude fibre

Crude fibre was determined by using AOAC (1999) official method 920.86. Ankom fibre analyzer (Model ANKOM 220, USA) was used for the determination of crude fibre. The sample of 1.0 g was digested in the fibre analyzer by dilute sulphuric acid (0.125 M H<sub>2</sub>SO<sub>4</sub>) for 30 min and washed with hot water. The residues were then digested by dilute alkali (0.125 M KOH) for 30 min and washed by hot water. Digested residues were dried in the oven 105°C for 5 h, cooled and weighed. The residues were then placed in muffle furnace and incinerated at 550°C for 2 h, cooled and weighed again. Total fibre content was taken as the difference between the residues before and after Incineration

$$\%C.F = \frac{(\text{Weight of sample residues before incineration} - \text{Weight after})g}{\text{Weight of dry sample taken for determination}(g)} \times 100 \dots\dots\dots(iv)$$

### 3.3.2.5 Carbohydrate

Carbohydrate was calculated as a percentage difference using the formula:

$$\% \text{ Carbohydrate} = 100 \% - (\% \text{ protein} + \% \text{ crude fibre} + \% \text{ crude fat} + \% \text{ Ash}) \dots\dots(vi)$$

### 3.3.2.6 Energy

The energy content was calculated using the Atwater's conversion factors. Thus energy values were obtained by multiplying % fat by factor 9 and % protein and % carbohydrate by factor 4 each (AOAC, 1990).

$$\text{Energy content} = [(\% \text{ Carbohydrate} \times 4) + (\% \text{ Fat} \times 9) + (\% \text{ protein} \times 4)] \dots\dots\dots(vii).$$

### 3.3.2.7 Mineral composition

Mineral composition; calcium, iron, zinc, magnesium, potassium, and copper, was determined by atomic absorption spectrophotometer (UNICAM, Cambridge, United

Kingdom) using procedure of method number 968.08 as described by AOAC 1999. From each sample 5 g was measured in a pre-dried and weighed crucibles then incinerated at 550°C overnight to ash. The ash was dissolved in 6 N HCl and left for 12 h to allow extraction of minerals.

### **3.3.3 Digestibility**

The gruel digestibility was determined according to the procedure described by Sabahel *et al.* (2010). The method is done by ping the digestible crude protein into solution using the pepsin enzyme in HCl acid medium. In the digestion block (420°C) the samples are digested for 45-60 min. The crude protein of the insoluble residues is then determined using the Kjeldahl method.

### **3.4 Results and Discussion**

Chemical composition of sorghum-pigeon peas based instant porridge flour (g/100 g dry weight) is summarized in Table 3.2. The composition is compared with the Tanzania standard for processed cereal based foods for infants and young children (TZS 180: 2013) indicated by the Tanzania Bureau of Standards (Table 3.1). These standards are based on CODEX 2006.

**Table 3.1: Requirements for processed cereal-based foods for infants and young children**

Characteristics	Requirements
Moisture content, % by mass, max.	Products ready for use: 4.0 Products for further processing: 8.0
Total protein (quality at least 70 % that of casein) % by mass, min.	14.0
Fat, % by mass, max.	8.5
Total carbohydrates, % by mass, min.	60.0
Total ash, % by mass, max.	5.0
Ash insoluble in HCl, % by mass, max.	0.05
Crude fibre (on dry basis), % by mass, max.	5
Vitamin A, IU/100 g, min.	500
Vitamin C mg/100 g, min.	25
Added Vitamin D, IU/100 g.	300 to 800
Thiamine (as hydrochloride) mg/100 g, min.	0.5
Nicotinic acid, mg/100 g, min.	5
Calcium, mg/100 g, max.	1.0
Phosphorus mg/100 g, min.	250
Iron mg/100 g, min.	10

Source: TZS 180: 2013.

### 3.4.1 Crude fat

The crude fat ranged from 0.5g/100 g DM in *Tegemeo*-pigeon peas (70:30) to 3.6 g/100 g DM in *Pato* sorghum, a decrease in fat content was observed between the milled sorghum flour samples and corresponding extruded sorghum in all varieties. This shows that extrusion decrease crude fat, this could be associated with the shear pressure and high temperatures used cause breakdown of the lipid polymerization in the food sample hence the extruded product reduced in fat (Belitz *et al.*, 2009).

**Table 3.2: Proximate composition (g/100 g DM), energy (kcal/ 100 g) and protein digestibility (%) of sorghum-pigeon peas instant porridge flour**

Sample	Crude fibre	Crude fat	Ash	Crude protein	Carbohydrate	Energy	Digestibility
<i>Pato</i> sorghum (milled)	7.7 ± 0.2 <sup>bcd</sup>	3.3 ± 0.8 <sup>b</sup>	1.4 ± 0.0 <sup>bc</sup>	10.0 ± 0.2 <sup>b</sup>	80.2 ± 0.7 <sup>cde</sup>	396 ± 2.7 <sup>e</sup>	8.2 ± 0.1 <sup>bc</sup>
<i>Pato</i> sorghum	6.3 ± 0.2 <sup>bc</sup>	3.6 ± 0.6 <sup>b</sup>	1.7 ± 0.1 <sup>cd</sup>	10.9 ± 0.0 <sup>d</sup>	82.0 ± 0.4 <sup>de</sup>	397 ± 2.8 <sup>e</sup>	8.0 ± 0.1 <sup>bc</sup>
<i>Pato</i> -pigeon peas (75:25)	6.9 ± 1.9 <sup>bc</sup>	2.8 ± 2.6 <sup>b</sup>	2.4 ± 0.2 <sup>ef</sup>	12.2 ± 0.0 <sup>j</sup>	75.8 ± 0.5 <sup>bc</sup>	376 ± 21.3 <sup>bcde</sup>	8.9 ± 0.1 <sup>d</sup>
<i>Pato</i> -pigeon peas (70:30)	6.7 ± 0.7 <sup>bc</sup>	0.7 ± 0.1 <sup>a</sup>	0.6 ± 0.0 <sup>a</sup>	12.6 ± 0.0 <sup>k</sup>	79.4 ± 0.8 <sup>bcde</sup>	374 ± 1.9 <sup>bcde</sup>	10.2 ± 0.0 <sup>hi</sup>
<i>Wahi</i> sorghum (milled)	7.3 ± 0.6 <sup>bcd</sup>	3.2 ± 0.2 <sup>b</sup>	1.4 ± 0.1 <sup>bcd</sup>	11.0 ± 0.0 <sup>de</sup>	79.1 ± 0.3 <sup>bcde</sup>	366 ± 6.7 <sup>bcd</sup>	9.9 ± 0.0 <sup>fgh</sup>
<i>Wahi</i> sorghum	5.2 ± 2.5 <sup>bc</sup>	0.6 ± 0.6 <sup>a</sup>	1.8 ± 0.0 <sup>d</sup>	11.3 ± 0.0 <sup>ef</sup>	79.1 ± 3.0 <sup>bcde</sup>	389 ± 2.8 <sup>de</sup>	10.1 ± 0.0 <sup>ghi</sup>
<i>Wahi</i> -pigeon peas (75:25)	4.9 ± 0.2 <sup>ab</sup>	1.0 ± 0.2 <sup>a</sup>	2.3 ± 0.1 <sup>e</sup>	14.1 ± 0.5 <sup>m</sup>	77.6 ± 0.6 <sup>bcd</sup>	375 ± 2.4 <sup>bcde</sup>	9.6 ± 0.7 <sup>ef</sup>
<i>Wahi</i> -pigeon peas (70:30)	5.4 ± 0.0 <sup>bc</sup>	0.6 ± 0.1 <sup>a</sup>	2.6 ± 0.0 <sup>f</sup>	13.2 ± 0.0 <sup>l</sup>	78.2 ± 0.1 <sup>bcde</sup>	370 ± 0.4 <sup>bcde</sup>	9.7 ± 0.0 <sup>efg</sup>
<i>Hakika</i> sorghum (milled)	8.6 ± 0.1 <sup>cde</sup>	2.9 ± 0.1 <sup>b</sup>	1.3 ± 0.0 <sup>b</sup>	11.7 ± 0.1 <sup>gh</sup>	78.4 ± 0.0 <sup>bcde</sup>	362 ± 11.9 <sup>bcd</sup>	9.7 ± 0.0 <sup>efg</sup>
<i>Hakika</i> sorghum	5.6 ± 3.2 <sup>def</sup>	0.8 ± 0.2 <sup>a</sup>	1.7 ± 0.1 <sup>cd</sup>	10.6 ± 0.2 <sup>c</sup>	78.6 ± 3.4 <sup>bcde</sup>	387 ± 0.8 <sup>de</sup>	8.8 ± 0.1 <sup>d</sup>
<i>Hakika</i> -pigeon peas (75:25)	6.4 ± 0.1 <sup>bc</sup>	0.6 ± 0.3 <sup>a</sup>	2.4 ± 0.1 <sup>ef</sup>	11.9 ± 0.1 <sup>hi</sup>	67.7 ± 0.4 <sup>a</sup>	323 ± 0.9 <sup>a</sup>	10.4 ± 0.0 <sup>i</sup>
<i>Hakika</i> -pigeon peas (70:30)	7.3 ± 2.3 <sup>bcd</sup>	1.1 ± 0.2 <sup>a</sup>	2.4 ± 0.2 <sup>ef</sup>	12.7 ± 0.0 <sup>k</sup>	74.6 ± 2.2 <sup>bc</sup>	358 ± 7.1 <sup>bc</sup>	9.4 ± 0.0 <sup>e</sup>
<i>Tegemeo</i> sorghum (milled)	8.5 ± 2.8 <sup>cde</sup>	3.2 ± 0.1 <sup>b</sup>	1.4 ± 0.0 <sup>bcd</sup>	9.9 ± 0.0 <sup>b</sup>	79.9 ± 3.0 <sup>cde</sup>	388 ± 10.7 <sup>de</sup>	8.2 ± 0.0 <sup>bc</sup>
<i>Tegemeo</i> sorghum	6.1 ± 0.4 <sup>bc</sup>	1.2 ± 0.0 <sup>a</sup>	1.7 ± 0.0 <sup>cd</sup>	11.5 ± 0.1 <sup>fg</sup>	73.6 ± 0.3 <sup>ab</sup>	351 ± 1.7 <sup>ab</sup>	7.4 ± 0.0 <sup>a</sup>
<i>Tegemeo</i> -pigeon peas (75:25)	7.2 ± 0.4 <sup>bcd</sup>	1.1 ± 0.1 <sup>a</sup>	2.3 ± 0.1 <sup>e</sup>	12.3 ± 0.2 <sup>j</sup>	79.2 ± 0.0 <sup>bcde</sup>	375 ± 1.7 <sup>bcde</sup>	11.1 ± 0.0 <sup>j</sup>
<i>Tegemeo</i> -pigeon peas (70:30)	8.9 ± 2.3 <sup>cde</sup>	0.5 ± 0.4 <sup>a</sup>	2.6 ± 0.0 <sup>ef</sup>	13.3 ± 0.0 <sup>l</sup>	74.7 ± 2.7 <sup>bc</sup>	356 ± 7.5 <sup>b</sup>	11.8 ± 0.1 <sup>k</sup>
<i>Macia</i> sorghum (milled)	5.9 ± 0.1 <sup>ab</sup>	2.9 ± 0.1 <sup>b</sup>	1.5 ± 0.0 <sup>bcd</sup>	9.5 ± 0.2 <sup>a</sup>	80.1 ± 0.4 <sup>cde</sup>	384 ± 0.1 <sup>cde</sup>	7.9 ± 0.0 <sup>b</sup>
<i>Macia</i> sorghum	3.6 ± 0.3 <sup>a</sup>	1.1 ± 0.6 <sup>a</sup>	1.6 ± 0.1 <sup>bcd</sup>	9.9 ± 0.0 <sup>b</sup>	83.8 ± 0.3 <sup>e</sup>	385 ± 4.2 <sup>cde</sup>	8.3 ± 0.3 <sup>c</sup>
<i>Macia</i> -pigeon peas (75:25)	5.1 ± 0.6 <sup>bc</sup>	1.1 ± 0.1 <sup>a</sup>	2.3 ± 0.0 <sup>ef</sup>	11.4 ± 0.0 <sup>f</sup>	80.1 ± 0.5 <sup>cde</sup>	375 ± 3.1 <sup>bcde</sup>	8.6 ± 0.1 <sup>d</sup>
<i>Macia</i> -pigeon peas (70:30)	6.1 ± 0.5 <sup>bc</sup>	0.9 ± 0.1 <sup>a</sup>	2.5 ± 0.1 <sup>ef</sup>	12.1 ± 0.1 <sup>ij</sup>	78.4 ± 0.5 <sup>bcde</sup>	370 ± 1.4 <sup>bcd</sup>	10.3 ± 0.1 <sup>i</sup>

Values are expressed as mean ± standard deviation (n=2) on dry basis. Mean values with different super script letters along the column are significantly different at p ≤ 0.05.

It was observed a significant difference in fat content between the milled sorghum samples and the extruded formulated samples; low levels of fat content were observed in extruded ones. There was no significance difference in fat content observed in formulated flour samples in all sorghum varieties. Among the varieties, higher levels were observed in *Pato* variety than others.

The TZS 180:2013 set a maximum of 8.5% of fat content in complementary foods, where by all the samples under study were within the set levels. The study by Byaruhanga *et al.* (2014) showed similar results that extrusion decrease the fat content of the food samples. The study by Davis (2004) reported the use of extrusion in reducing the fat content of soybeans.

### **3.4.2 Ash**

The ash content indicates the inorganic minerals present in the sample; the high level of ash indicated the presence of high levels of minerals. From the study the range of minerals was from 0.6 g/100 g DM in *Pato*-pigeon peas (70:30) to 2.6 g/100 g DM in *Wahi*-pigeon peas (70:30) sample. There was a significant difference ( $p \leq 0.05$ ) in minerals between the milled sorghum samples of all varieties and the extruded formulated ones. This difference could be due to the extrusion temperatures and shear pressure that resulted in the increase in minerals availability. An increase in minerals content as pigeon peas were added to all samples of sorghum varieties was observed. This could be influenced by the nutrients richness of peas. The ash content increased in all formulations of sorghum varieties was likely similar.

According to the TZS 180:2013, 5% is set as the maximum percentage of minerals content in the flour. All the formulated samples under study had met the mineral content

level set because the levels did not exceed 5%. The level of ash in food is an important nutritional indicator for mineral density and quality parameter for contamination, especially with foreign matter (Fennema, 1996). Ndibalema (2011) found that as sardines and soybeans were added to the plain sorghum, the ash content increased significantly.

### **3.4.3 Crude protein**

The range of protein observed were 9.5g/100g DM to 14.1g/100g DM for milled *Macia* sorghum and *Wahi*-pigeon peas (75:25), respectively. As compared to milled samples of sorghum varieties there was a significant increase in protein content for all extruded plain sorghum varieties formulation. An increase was noted as pigeon peas were added to the sorghum varieties. Upon extrusion temperature and pressure, protein is denatured, anti-nutritional factors are destroyed hence its digestibility and bio availability increase (Yusuf *et al.*, 2018). Pelembe *et al.* (2002) reported similar increases in protein content of sorghum composite flours with increasing cowpea content.

Despite the increase in protein content upon extrusion and the blend, all the samples under study had protein content below the minimum level stipulated in the Tanzania Bureau of Standards under TZS 180:2013 for processed cereal-based complementary foods which is 14%. Byaruhanga *et al.* (2014) found that addition of soy-flour increased the protein content of extrudates since soy-flour contained more protein than the sorghum. Protein is very important in general body growth and maintenance of body tissues; it assists the enzymes action in the body which catalyze different metabolic reactions (FAO/WHO/UNU, 1985).

### **3.4.4 Crude fibre**

Crude fibre ranged from 3.6 g/100 g DM in *Macia* sorghum to 8.9 g/100 g DM in *Tegemeo*-pigeon peas (70:30). There was a decrease in fibre content between milled and

corresponding extruded sorghum for all the varieties; because, larger fragments of fibre molecules could sheared off during extrusion (Leszek, 2011). There was no significant difference ( $p \leq 0.05$ ) in fibre content among the varieties.

Tanzania Bureau of Standards under TZS 180:2013 indicated that complementary foods should not contain more than 5 g of crude fibre per 100 g of dry edible matter as the standard level set for fibre content. Most of the formulations had fibre content beyond set levels except for *Macia* sorghum and *Wahi*-pigeon peas (75:25) which fell within the range.

Sorghum is rich in fibre content, the sorghum seed coat contain higher amount than other parts (Dykes and Rooney, 2006). During processing the samples were milled without dehulling. Therefore, despite extrusion the fibre content was still beyond range. The study by Belitz *et al.* (2009) reported that the reduction in fibre contents could be attributed by high shear pressure and temperature conditions of extrusion resulting in breakdown of fibre and interaction with other nutrient components. Fibre is important in prevention of constipation, overweight, cardiovascular diseases, diabetes and colon cancer however too much of it for older infants and young children increase dietary bulkiness, hence limiting adequate food intake by infants and young children (FAO, 1985).

#### **3.4.5 Carbohydrate**

The carbohydrate content of the samples under study ranged from 67.7 g/100 g DM in *Hakika*-pigeon peas (75:25) to 83.8 g/100 g DM in *Macia* sorghum. There was no significant difference ( $p \leq 0.05$ ) in carbohydrate content among the milled samples of all varieties, which indicated that the varieties of sorghum had similar carbohydrates composition. Carbohydrate content increased upon extrusion.

High temperature and pressure conditions during extrusion tend to increase the rate of gelatinization (Yusuf *et al.*, 2018). The possible cause of the increased carbohydrate content of the extruded might be due to starch degradation into dextrans and simple sugars like free glucose (Yusuf *et al.*, 2018). A decrease was observed as pigeon peas were added. This agrees with Sefah-dedeh *et al.* (2001) which reported that legumes addition reduces carbohydrate content of cereal based formulation.

According to the Tanzania Bureau of Standards, the carbohydrate content should be above 60%. From the study all the samples were above the standards set. Pelembe *et al.* (2002) observed that prior extrusion, sorghum had low starch, as the percentage of cowpeas increased, and the total starch decreased in the extrudates. This concludes that the carbohydrate content of cereals increases upon extrusion but reduced as legumes are added.

### **3.4.6 Energy**

The range of 323 kcal/100 g DM in *Hakika*-pigeon pea (75:25) to 397 kcal/100 g DM in milled *Pato* sorghum was observed. There was no significant difference ( $p \leq 0.05$ ) in energy levels among the milled sorghum samples of all varieties. All the samples had energy levels below 400 kcal/100g which is the minimum value specified by CODEX (2006). This was influenced by the samples used to make the formulations, that is individually sorghum and pigeon peas had energy values below 400 kcal/ 100 g which affected the composite energy levels. However, Ndibalema (2011) reported that enrichment of sorghum-based formulations with soybean and ground sardines significantly improved ( $p < 0.05$ ) their energy densities above 400 kcal/100 g. The author observed that apart from the plain sorghum products, all the composite supplementary products with high proportions of soybean (sorghum-soybean formulations) had higher

energy density because soybean is rich in fat and protein which contributes to energy density.

### **3.4.7 Digestibility**

The observed digestibility ranged from 7.4 g/100 g DM in *Tegemeo* sorghum to 11.8 g/100 g DM in *Tegemeo*-pigeon peas (70:30). There was an increase in protein digestibility for the extruded samples compared to milled sorghum samples of all varieties. Protein digestibility indicates the proportion of a food protein ingested which is digested and absorbed in the gastrointestinal tract (WHO/FAO/UNU, 2007).

In extrusion cooking protein in food products is denatured, which exposes more sites for proteolytic attack hence improves *in vitro* protein digestibility. The reduction of phytates and decrease of trypsin inhibitor after extrusion cooking possibly reduces the adverse effect of these anti-nutrients on protein digestibility (Batista *et al.*, 2010).

The report by Osman (2004) explained the improvement in the *in vitro* protein digestibility of sorghum samples was due to the reduction in anti-nutritional factors as a result of fermentation and cooking. Similar results were obtained by Mohammed *et al.* (2011) in which the *in vitro* protein digestibility of sorghum flour, fermented dough were improved upon fermentation and cooking. The study by Anyago *et al.* (2011) reported that the *in vitro* protein digestibility values of extruded composite flours were higher than the 70:30 sorghum-cowpea flour cooked into unfermented and fermented porridge.

### **3.4.8 Mineral composition**

The mineral compositions of sorghum-pigeon peas based instant porridge flour are shown in Table 3.3.

**Table 3.3 Mineral composition of sorghum-pigeon peas instant porridge flour (mg/100 g DM)**

<b>Sample</b>	<b>Calcium</b>	<b>Magnesium</b>	<b>Potassium</b>	<b>Copper</b>	<b>Zinc</b>	<b>Iron</b>
<i>Pato</i> sorghum (milled)	268.9±9.2 <sup>a</sup>	259.5±1.3 <sup>ab</sup>	382.1±10.9 <sup>ab</sup>	0.2±0.0 <sup>b</sup>	2.2±0.0 <sup>ab</sup>	4.3±0.1 <sup>bc</sup>
<i>Pato</i> sorghum	278.9±7.9 <sup>abcd</sup>	289.8±11.5 <sup>de</sup>	394.7±5.4 <sup>ab</sup>	0.3±0.0 <sup>d</sup>	2.4±0.1 <sup>bc</sup>	4.6±0.1 <sup>bcd</sup>
<i>Pato</i> -pigeon peas (75:25)	362.2±4.5 <sup>hi</sup>	321.2±4.8 <sup>g</sup>	677.3±10.1 <sup>d</sup>	0.4±0.0 <sup>gh</sup>	3.2±0.0 <sup>efgh</sup>	6.8±0.2 <sup>fgh</sup>
<i>Pato</i> -pigeon peas (70:30)	382.9±8.4 <sup>ij</sup>	336.2±2.3 <sup>g</sup>	804.2±11.5 <sup>g</sup>	0.4±0.0 <sup>j</sup>	3.8±0.0 <sup>i</sup>	8.5±0.1 <sup>j</sup>
<i>Wahi</i> sorghum (milled)	269.1±1.2 <sup>ab</sup>	243.2±2.7 <sup>a</sup>	381.1±2.8 <sup>ab</sup>	0.3±0.0 <sup>d</sup>	1.9±0.1 <sup>a</sup>	3.1±0.1 <sup>a</sup>
<i>Wahi</i> sorghum	280.5±1.9 <sup>cde</sup>	262.5±7.7 <sup>abc</sup>	398.1±3.1 <sup>b</sup>	0.3±0.0 <sup>d</sup>	2.0±0.1 <sup>ab</sup>	3.5±0.0 <sup>ab</sup>
<i>Wahi</i> -pigeon peas (75:25)	373.5±0.3 <sup>hij</sup>	298.6±2.3 <sup>ef</sup>	639.4±1.6 <sup>c</sup>	0.4±0.0 <sup>h</sup>	3.0±0.2 <sup>def</sup>	5.5±0.0 <sup>cde</sup>
<i>Wahi</i> -pigeon peas (70:30)	395.6±4.9 <sup>j</sup>	320.5±15.0 <sup>g</sup>	868.4±4.7 <sup>h</sup>	0.4±0.0 <sup>hij</sup>	3.5±0.2 <sup>ghi</sup>	7.9±0.4 <sup>hij</sup>
<i>Hakika</i> sorghum (milled)	270.6±1.2 <sup>abc</sup>	262.9±0.2 <sup>abc</sup>	370.1±6.8 <sup>a</sup>	0.2±0.0 <sup>c</sup>	1.9±0.1 <sup>a</sup>	3.8±0.1 <sup>ab</sup>
<i>Hakika</i> sorghum	287.6±5.4 <sup>bcde</sup>	274.1±0.9 <sup>bcd</sup>	390.1±3.3 <sup>ab</sup>	0.3±0.0 <sup>e</sup>	2.2±0.2 <sup>ab</sup>	3.9±0.0 <sup>ab</sup>
<i>Hakika</i> -pigeon peas (75:25)	301.7±2.2 <sup>de</sup>	297.8±0.8 <sup>e</sup>	690.8±4.9 <sup>de</sup>	0.4±0.0 <sup>hi</sup>	2.8±0.0 <sup>cd</sup>	5.8±0.1 <sup>def</sup>
<i>Hakika</i> -pigeon peas (70:30)	334.1±1.1 <sup>fg</sup>	324.9±7.3 <sup>g</sup>	735.3±11.8 <sup>f</sup>	0.4±0.0 <sup>i</sup>	3.1±0.1 <sup>defg</sup>	8.0±0.8 <sup>hij</sup>
<i>Tegemeo</i> sorghum (milled)	273.3±0.7 <sup>abc</sup>	263.9±1.3 <sup>abc</sup>	384.1±10.5 <sup>ab</sup>	0.1±0.0 <sup>a</sup>	2.4±0.2 <sup>bc</sup>	3.7±0.0 <sup>ab</sup>
<i>Tegemeo</i> sorghum	281.2±0.7 <sup>abcd</sup>	278.5±3.6 <sup>cde</sup>	400.7±5.8 <sup>b</sup>	0.2±0.0 <sup>bc</sup>	2.6±0.0 <sup>cde</sup>	3.9±0.1 <sup>ab</sup>
<i>Tegemeo</i> -pigeon peas (75:25)	310.1±12.9 <sup>ef</sup>	319.3±0.2 <sup>fg</sup>	721.6±8.9 <sup>ef</sup>	0.4±0.0 <sup>f</sup>	3.6±0.0 <sup>hi</sup>	5.9±0.1 <sup>ef</sup>
<i>Tegemeo</i> -pigeon peas (70:30)	349.9±5.5 <sup>gh</sup>	332.0±1.5 <sup>g</sup>	898.7±12.5 <sup>hi</sup>	0.4±0.0 <sup>ij</sup>	3.9±0.1 <sup>i</sup>	6.1±0.0 <sup>efg</sup>
<i>Macia</i> sorghum (milled)	281.4±0.5 <sup>abc</sup>	255.1±1.2 <sup>ab</sup>	378.9±12.1 <sup>ab</sup>	0.2±0.0 <sup>bc</sup>	2.2±0.0 <sup>ab</sup>	3.5±0.1 <sup>ab</sup>
<i>Macia</i> sorghum	293.9±6.8 <sup>bcde</sup>	270.3±1.1 <sup>bcd</sup>	398.6±1.6 <sup>b</sup>	0.2±0.0 <sup>c</sup>	2.7±0.0 <sup>cd</sup>	3.9±0.1 <sup>ab</sup>
<i>Macia</i> -pigeon pea(75:25)	320.4±2.4 <sup>ef</sup>	297.9±2.9 <sup>e</sup>	779.7±7.7 <sup>g</sup>	0.4±0.0 <sup>fg</sup>	3.1±0.0 <sup>defg</sup>	7.2±0.7 <sup>ghi</sup>
<i>Macia</i> -pigeon pea(70:30)	358.0±1.5 <sup>ghi</sup>	325.4±0.6 <sup>g</sup>	915.2±7.5 <sup>i</sup>	0.4±0.0 <sup>ij</sup>	3.3±0.0 <sup>fgh</sup>	8.2±0.6 <sup>ij</sup>

Values are expressed as mean± standard deviation (n=2) on dry basis. Mean values with different super script letters along the column are significantly different at p≤0.05.

#### **3.4.8.1 Calcium**

The calcium content ranged from 268.2 mg/100 g in milled *Pato* sorghum to 395.6 mg/100 g in *Wahi*-pigeon peas (70:30). For all sorghum varieties, the milled samples had no significant difference in calcium content. There was a significant increase ( $p \leq 0.05$ ) in the calcium content levels as pigeon peas were added in all sorghum varieties. According to FAO/WHO (1991), the calcium content for weaning food should have a minimum of 435 mg/100 g calcium levels in which all the formulated products were below the recommendation.

Therefore there is a need of inclusion of other calcium rich cereals so as to raise the levels and to ensure that calcium can be obtained from cheap cereals sources instead of milk source which is expensive. Calcium is an essential macronutrient in infants and young children for building bones and teeth, functioning of muscles and nerves, blood clotting and for immune defense (Whitney *et al.*, 1990).

#### **3.4.8.2 Magnesium**

The Magnesium content ranged from 243.2 mg/100 g in milled *Wahi* sorghum to 336.2 mg/100 g in *Pato*-pigeon peas (70:30). For all sorghum varieties, the milled sorghum samples had no significant difference in magnesium content. There was a significant increase in the levels as pigeon peas were added in all sorghum varieties. According to FAO/WHO (1991), the magnesium content for weaning food should have a minimum of 76 mg/100 g. All the formulated products were above the recommended levels for complemented foods.

These results indicate that the formulations are a good source of magnesium; hence, can help to offset the risk of diseases caused by its deficiency. Magnesium is a macronutrient

used for bone mineralization, teeth maintenance, building up of proteins, enzyme activities, normal muscular contractions and transmission of nerve impulses (Whitney *et al.*, 1990). Furthermore, high magnesium level causes calcium levels to be properly maintained, as magnesium increases calcium absorption in the body.

#### **3.4.8.3 Potassium**

The Potassium content ranged from 370.1 mg/100g in milled *Hakika* sorghum to 915.2 mg/100 g in *Macia*-pigeon peas (70:30). There was no significant difference ( $p \leq 0.05$ ) in potassium content among the milled sorghum varieties samples. There was an increase in the levels as pigeon peas were complemented in all sorghum varieties. According to CODEX, (2006) the potassium content for weaning food should have a minimum of 387.12 mg/100 g. Almost all the extruded formulated products were above the recommended levels for complemented foods. Potassium is an electrolyte essential in the homeostatic balance of body fluids. Excessive dietary intake of potassium has been reported to cause muscular weakness and vomiting in human subjects (Whitney *et al.*, 1990).

#### **3.4.8.4 Copper**

The Copper content ranged from 0.1 mg/100 g in milled *Tegemeo* sorghum to 0.4 mg/100 g in *Hakika*-pigeon peas (70:30). There was no significant difference ( $p \leq 0.05$ ) in copper content among the milled sorghum of all varieties. There was an increase in the copper content levels as pigeon peas were complemented in all sorghum varieties. According to FAO/WHO (1991) the copper content for weaning food should have minimum levels of 0.16 mg/100 g. Extruded formulated products were above the recommended levels for complemented foods.

Copper is essential in the absorption and utilization of iron during hemoglobin and myoglobin biosynthesis and forms part of several enzyme systems (King and Burgess, 1993). Adequate dietary copper is essential for the proper metabolism of iron, thus both dietary iron and copper play a major role in preventing anemia, a serious problem in developing countries (USCP and Lindsay, 2010).

#### **3.4.8.5 Zinc**

The Zinc content ranged from 1.9 mg/100 g in milled *Hakika* sorghum to 3.8 mg/100 g in *Pato*-pigeon peas (70:30). There was no significant difference in zinc content among the milled sorghum varieties samples ( $p \leq 0.05$ ). There was an increase in the zinc content levels as pigeon peas were complemented in all sorghum varieties. According to CODEX (1991) the zinc content for weaning food should have a minimum of 2.42 mg/100 g. The extruded formulated products in which pigeon peas were added had zinc content above the recommended levels. This indicates that inclusion of pigeon peas increases the zinc content in the formulation while extrusion process facilitates the availability of these minerals in the made formulation. Hence complementing the cereals and legumes perform better than individual cereal.

Zinc is an important micronutrient for infants and young children since it is used in the synthesis of enzymes, hormones, proteins and other materials that promote optimal physical and mental growth (King and Burgess, 1993). It enhances the body's immune system, thus, protecting children from infections. Therefore if infants are fed with these foods low in zinc, it would result in high risks of impaired growth and development in infants.

#### **3.4.8.6 Iron**

Iron is an essential micronutrient for the synthesis of hemoglobin (an oxygen carrier in the red blood cells), myoglobin (used for muscle contraction) and enzymes/coenzymes

(used in various metabolic pathways). Further-more iron enhances the body's immune system thus reducing infections and fostering proper functioning of other organs of the body (King and Burgess, 1993). Deficiency of iron results to prevalence of iron-deficiency anemia among infants and young.

From the study the Iron content ranged from 3.1 mg/100 g in milled *Wahi* sorghum to 8.5 mg/100 g in *Pato*-pigeon peas (70:30). There was a significant increase in the levels as pigeon peas were complemented in all sorghum varieties. The increase was significantly different ( $p \leq 0.05$ ) as compared to the samples that pigeon peas were not added. The CODEX (2006) set a minimum of 4.84 mg/100 g while the Tanzania bureau of standards TZS 180: 2013 recommend a minimum of 10.87 mg/100 g. All the samples were below the TBS set limits while all extruded formulated with pigeon peas products had the iron content above the recommended levels described by CODEX (2006). Unless other iron sources are incorporated, the formulations were not sufficient sources against the risk of anemia as required by the TBS iron content standard in food. Generally both extrusion and inclusion of pigeon pea increases the minerals bio availability for children as compared when sorghum is used alone.

### **3.5 Conclusions and Recommendations**

The study showed that the inclusion of pigeon peas raised the nutrients contents of sorghum varieties. At 70:30 ratios of sorghum-pigeon peas the nutrients fell within the CODEX and TBS food standards. Although the aim of inclusion of pigeon peas was to improve the nutrients composition particular protein, the study showed that the peas were not good source of protein sufficient to meet the TBS for protein content. Therefore, the inclusion of other legumes rich in protein could be an ideal alternative to improve the protein quality of white sorghum varieties.

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## CHAPTER FOUR

### 4.0 CONCLUSIONS AND RECOMMENDATIONS

The study showed the possibility of combination of white sorghum varieties with pigeon peas in different ratios so as to improve the nutrients composition and therefore increase the utilization of sorghum. It was observed that either of the white sorghum variety can be used to compliment with legumes since the varieties do not differ significantly in their nutrients composition.

Nutritionally, cereals perform better when combined with legumes such that the formulations in which pigeon peas were added had better nutritional composition than control plain white sorghum in all varieties. The combinations made at 70:30 sorghum-pigeon peas, had the best nutrient qualities. This implies that at 70:30 cereals-legumes ratio the nutrients composition are improved.

From the consumer test of the porridge made from the formulations, it is concluded that the instant porridge was less viscous, hence, easily drinkable especially for young children. It had the best sensory attributes that led to general acceptability. The porridge from extruded flour took short preparation time, therefore it could be a good alternative flour for children porridge.

Therefore complementing sorghum with pigeon peas with the aid of extrusion technology to make instant gruel flour is the best way of optimizing the utilization of sorghum and improving nutritional quality of sorghum. All of these ways all together

result in nutrient dense food for children; hence aid in combating diseases caused by low nutrients-foods given to them.

Since the study aimed to raise the protein quality of the formulations made from sorghum, it is recommended that other protein rich legumes such as soya beans, and groundnuts should be added to the formulations so as to raise the level of protein content to that required by the food regulatory authorities. By doing so it will increase the market of sorghum based products.

The adoption of extrusion cooking technology when preparing children foods especially porridge flour is recommended. This is because, the extrudates produced are easy to prepare and takes short time; therefore it will reduce the women work load and time they spend preparing food for their children. The extrudates are microbiologically free, therefore they are safe products; the anti- nutritional factors are destructed which results to increase the bio availability of nutrients in sorghum and its based products and therefore increase the sorghum utilization.